CERES Angular Distribution Model Working Group Report

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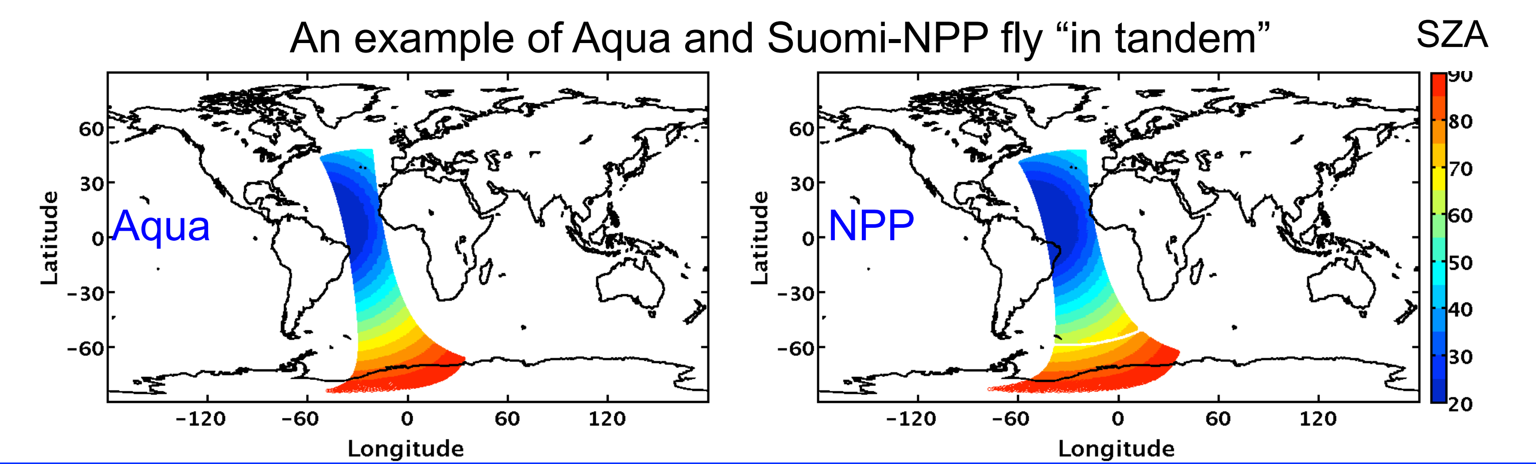
Outline

- Radiance comparisons between CERES NPP and CERES Aqua and plans to place them on the same radiometric scales;
- The importance of using consistent scene identification for developing and applying ADMs;
- Future improvement: ADMs over cloudy oceans;

Radiance comparison using simultaneous observations

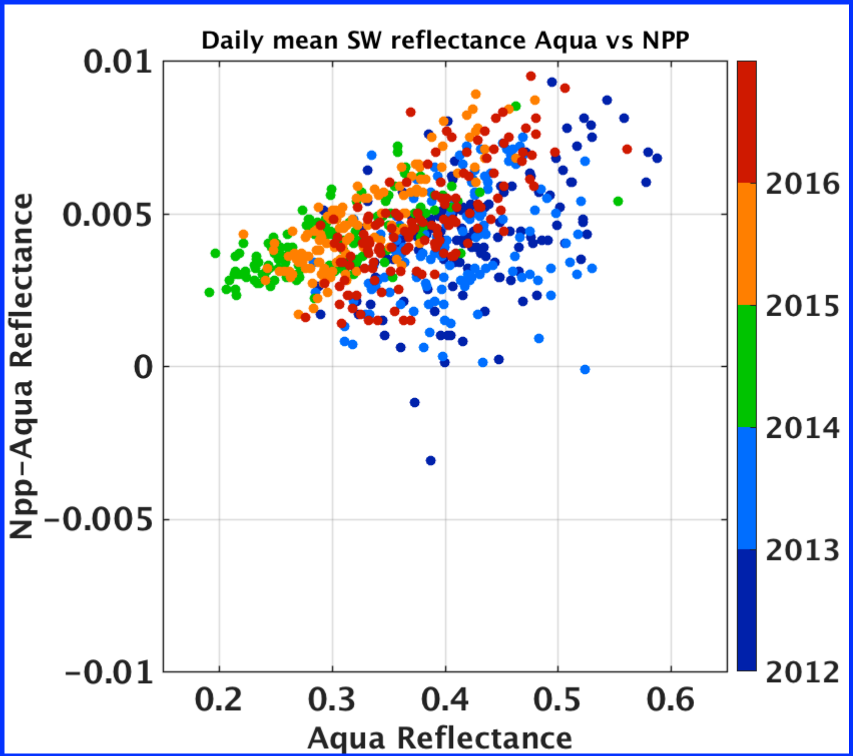
- About every 64 hours, Aqua and Suomi-NPP fly "in tandem".
- These simultaneous observations from Aqua and Suomi-NPP are matched to compare the SW and LW radiances using Ed4 Aqua SSF data and Ed1 NPP SSF data of 2012, 2013, 2014, 2015, 2016.
- Matching criteria used for SW and LW radiances are:
  - Latitude and longitude differences are less than 0.05 degree, solar zenith angle and viewing zenith angle differences are less than 2 degrees, relative azimuth angle difference is less than 5 degrees.
  - Using footprint center distance less than 5 km as the matching criteria produces similar results.

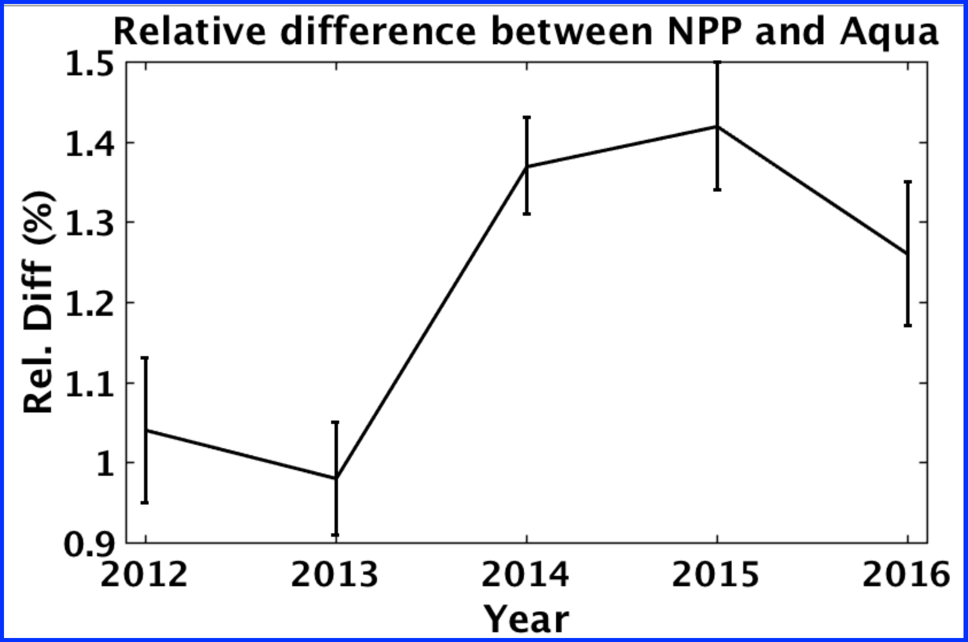


Method

- For each day that NPP and Aqua fly in tandem, average the matched radiances from Aqua and NPP and calculate the daily means of them
  - For all-sky, only days have 50 or more matched footprints are included
  - For clear-sky, only days have 5 or more matched footprints are included
- For a given year there are N days of matched daily mean radiance pairs from NPP and Aqua
- Mean radiances for Aqua and NPP are calculated for each year
- Mean radiance difference and the 95% confidence interval are calculated for each year

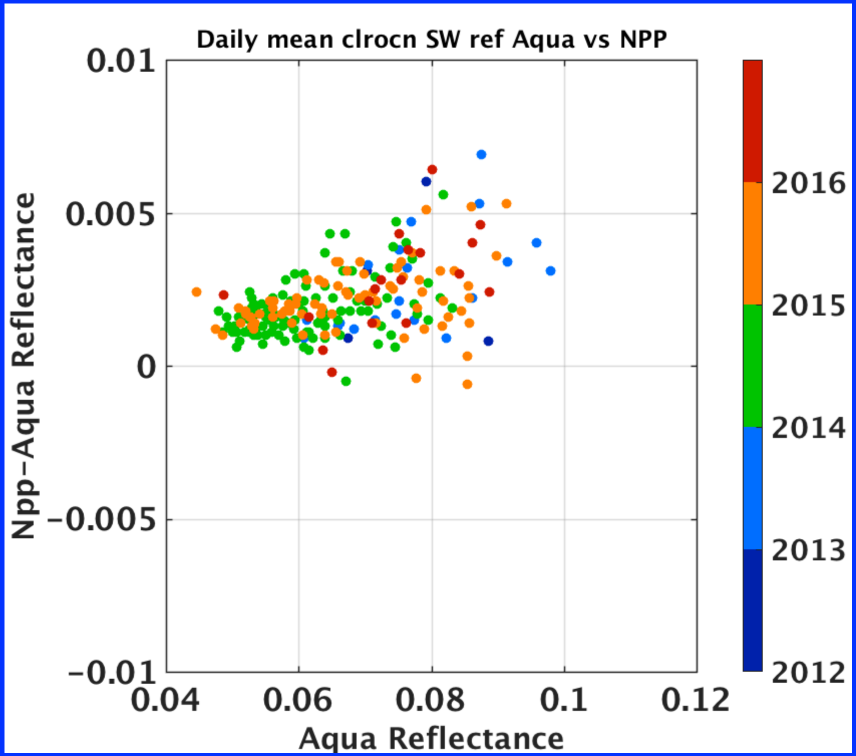
All-sky SW reflectance comparison

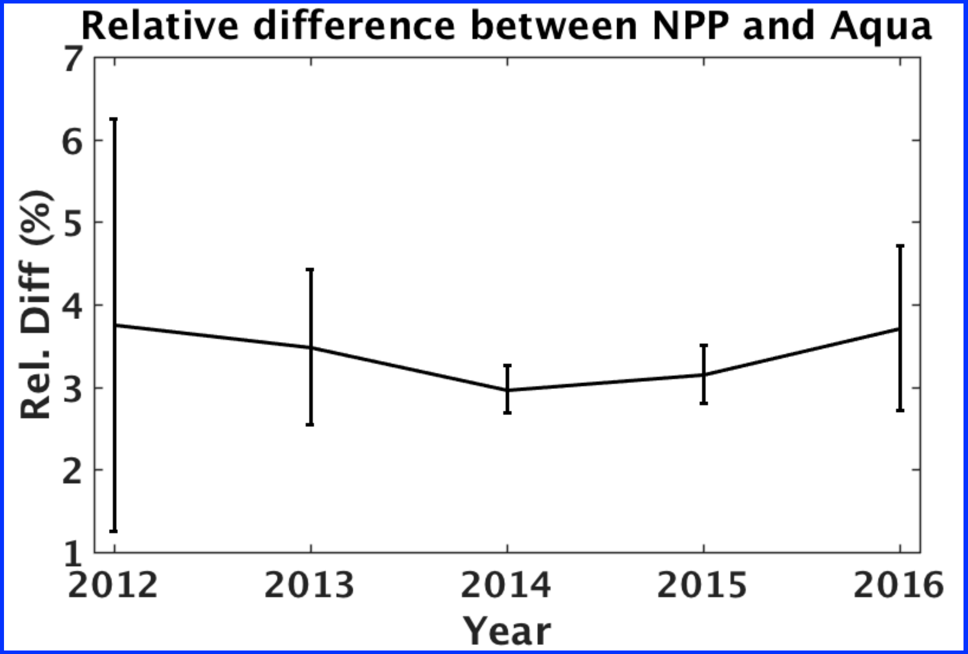




SW	N	Aqua	NPP	Dif std	Abs. Dif	Rel dif
2012	123	0.4290	0.4334	0.0022	0.0045±0.0005	1.04±0.09%
2013	139	0.4102	0.4142	0.0017	0.0040±0.0003	0.98±0.07%
2014	136	0.2939	0.2979	0.0011	0.0040±0.0002	1.37±0.06%
2015	133	0.3264	0.3310	0.0015	0.0046±0.0003	1.42±0.08%
2016	137	0.3860	0.3908	0.0020	0.0049±0.0003	1.26±0.09%

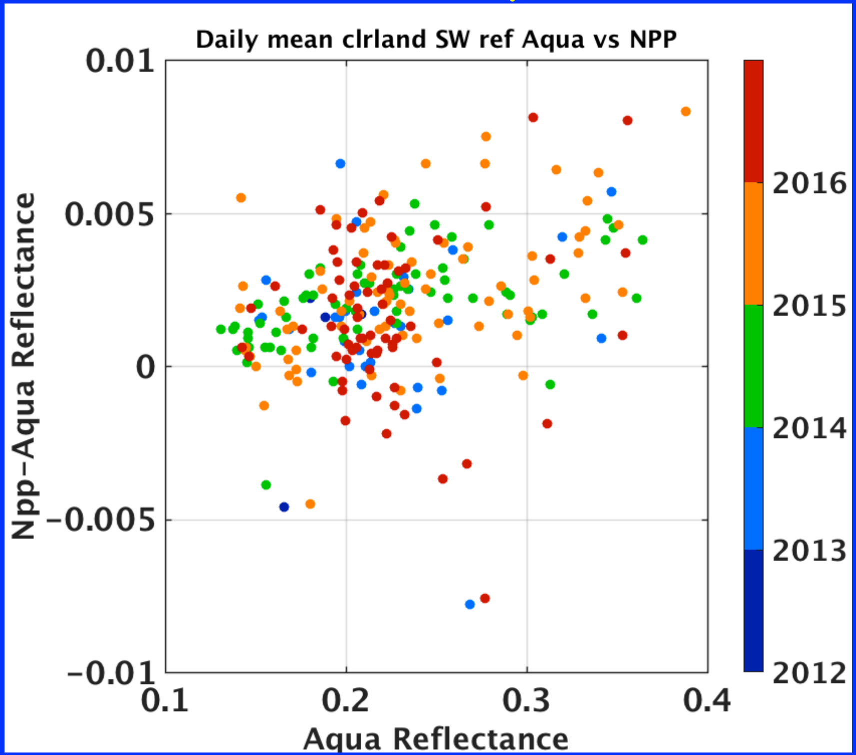
Clear-sky SW reflectance comparison over ocean

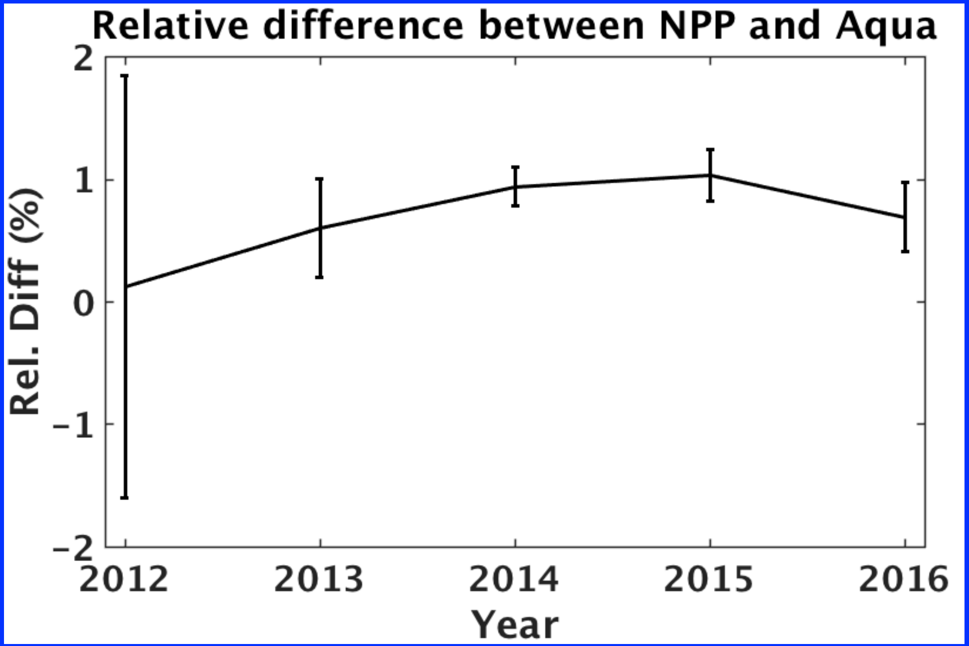




SW	N	Aqua	NPP	Dif std	Abs. Dif	Rel dif
2012	5	0.0864	0.0897	0.0024	0.0032±0.0022	3.75±2.50%
2013	20	0.0774	0.0801	0.0016	0.0027±0.0007	3.48±0.94%
2014	111	0.0615	0.0633	0.0009	0.0018±0.0002	2.97±0.29%
2015	51	0.0675	0.0696	0.0010	0.0021±0.0002	3.15±0.35%
2016	18	0.0741	0.0768	0.0016	0.0027±0.0007	3.71±1.00%

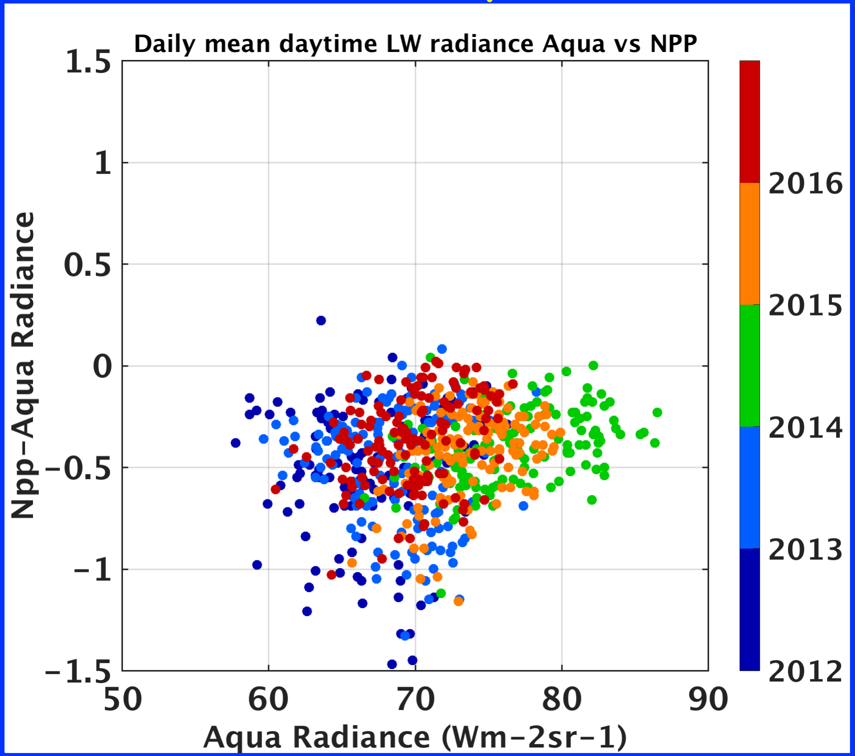
Clear-sky SW reflectance comparison over land

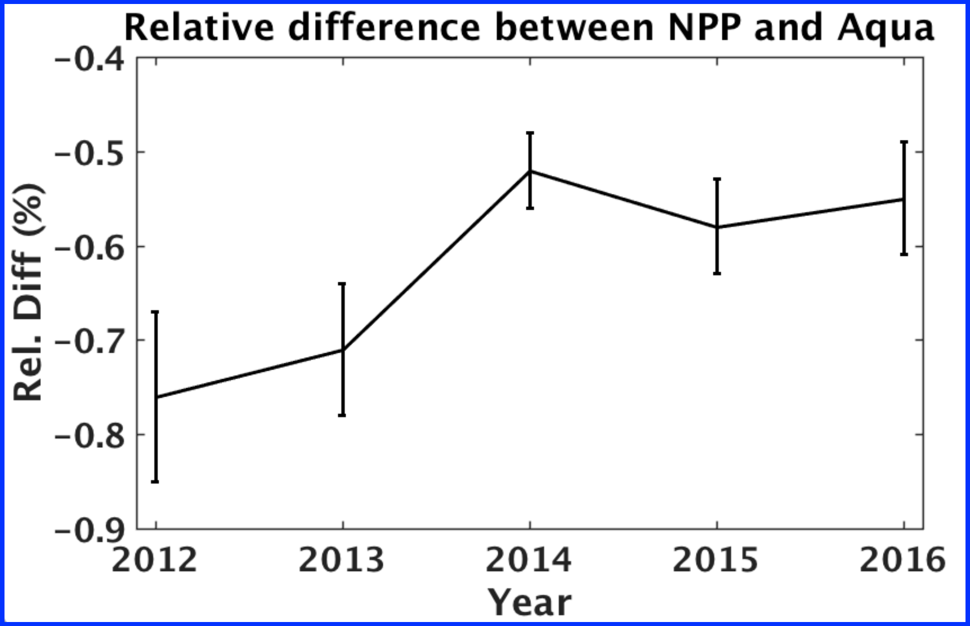




SW	N	Aqua	NPP	Dif std	Abs. Dif	Rel dif
2012	4	0.1860	0.1862	0.0032	0.0002±0.0032	0.12±1.72%
2013	31	0.2230	0.2244	0.0025	0.0013±0.0009	0.60±0.40%
2014	71	0.2222	0.2242	0.0015	0.0021±0.0004	0.94±0.16%
2015	78	0.2352	0.2376	0.0022	0.0024±0.0005	1.03±0.21%
2016	68	0.2225	0.2240	0.0026	0.0015±0.0006	0.69±0.28%

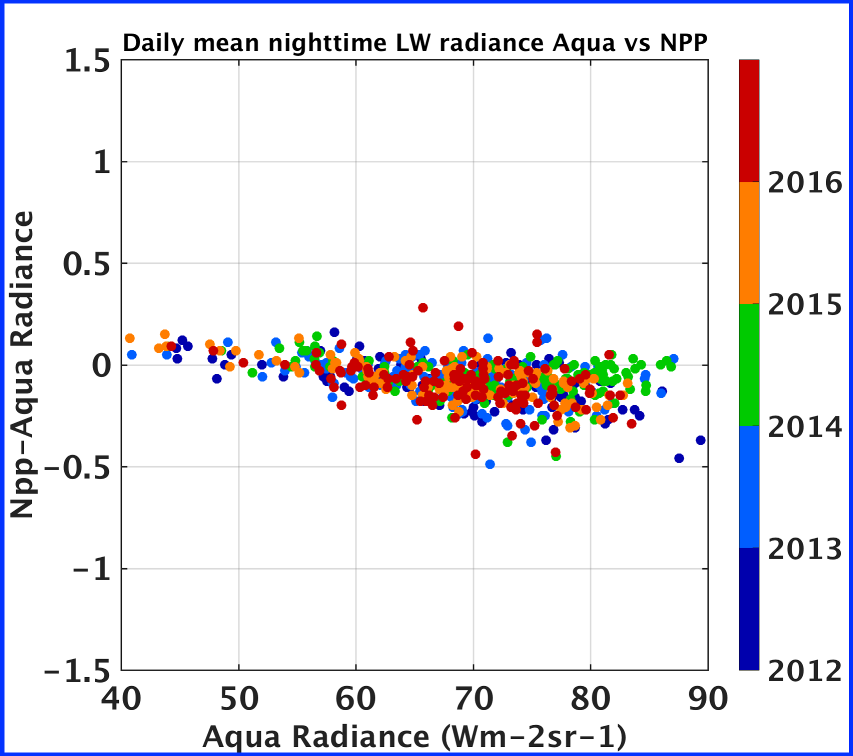
Daytime LW radiance comparison results

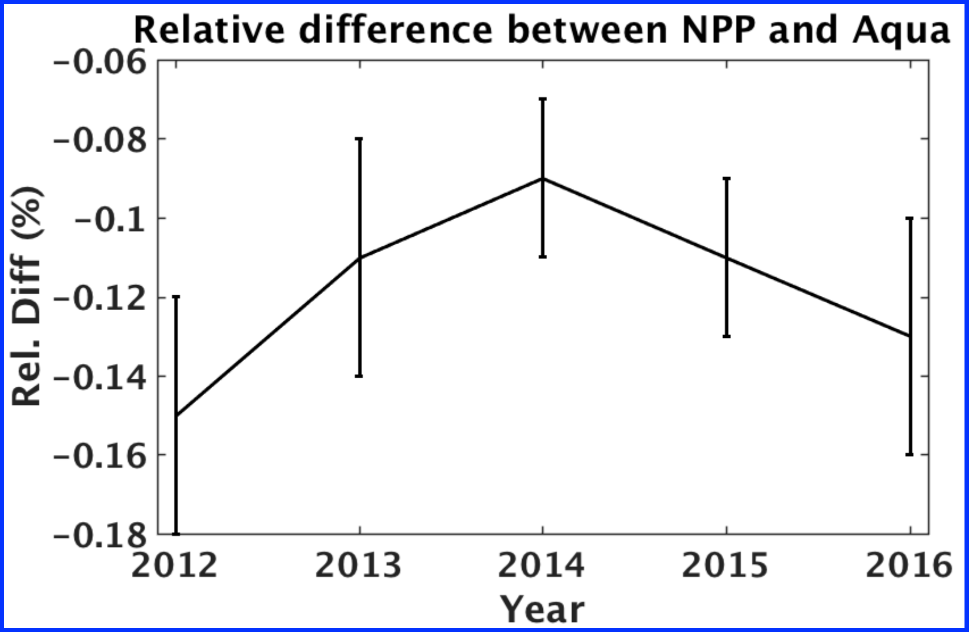




LW d	N	Aqua	NPP	Std dif	Abs. Dif	Rel. Dif
2012	122	66.89	66.36	0.336	-0.51±0.06	-0.76±0.09%
2013	139	68.51	68.02	0.285	-0.49±0.05	-0.71±0.07%
2014	136	76.98	76.58	0.182	-0.40±0.03	-0.52±0.04%
2015	133	73.83	73.40	0.214	-0.43±0.04	-0.58±0.05%
2016	137	69.74	69.36	0.249	-0.38±0.04	-0.55±0.06%

Nighttime LW radiance comparison





LW n	N	Aqua	NPP	Std. Diff	Abs. Dif	Rel. dif
2012	99	68.30	68.20	0.115	-0.10±0.02	-0.15±0.03%
2013	129	67.88	67.81	0.108	-0.07±0.02	-0.11±0.03%
2014	123	72.43	72.37	0.091	-0.06±0.02	-0.09±0.02%
2015	125	68.60	68.53	0.089	-0.08±0.02	-0.11±0.02%
2016	130	68.92	68.84	0.109	-0.09±0.02	-0.13±0.03%

Plans for placing CERES-NPP and CERES-Aqua on the same radiometric scale

- As the clear ocean comparisons show larger relative differences than all-sky comparisons, the beginning of the mission spectral response function for CERES-NPP will be refined to account for the scene dispersion;
- The new spectral response function will then be used to produce the interim CERES-NPP radiances to compare with the CERES-Aqua radiances using the same methodology presented here to generate the new CERES-NPP radiometric adjustment gains;
- The new spectral response function and the gains will be used to produce the Edition 2 CERES-NPP data.

Effects of inconsistent scene identification on flux

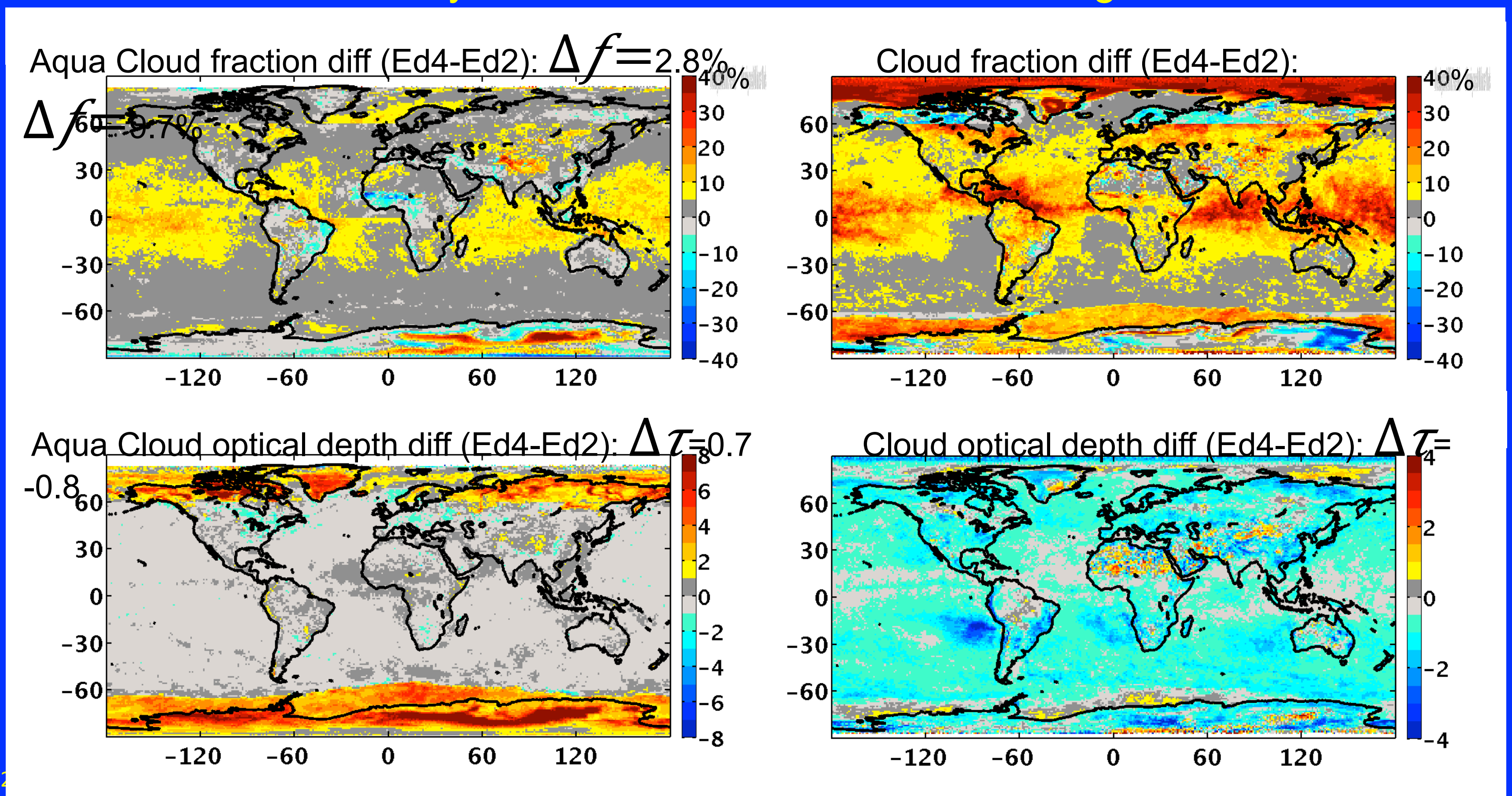
- Ed4 ADMs were developed using Ed4 cloud retrievals for scene identifications;
- Ed2 ADMs were developed using Ed2 cloud retrievals for scene identifications;
- Fluxes in Ed4 SSF were derived using the Ed4 ADMs;
- To assess the effects of inconsistent scene identification on flux uncertainty, Ed2 ADMs were applied to Ed4 SSF.

200410: Daytime

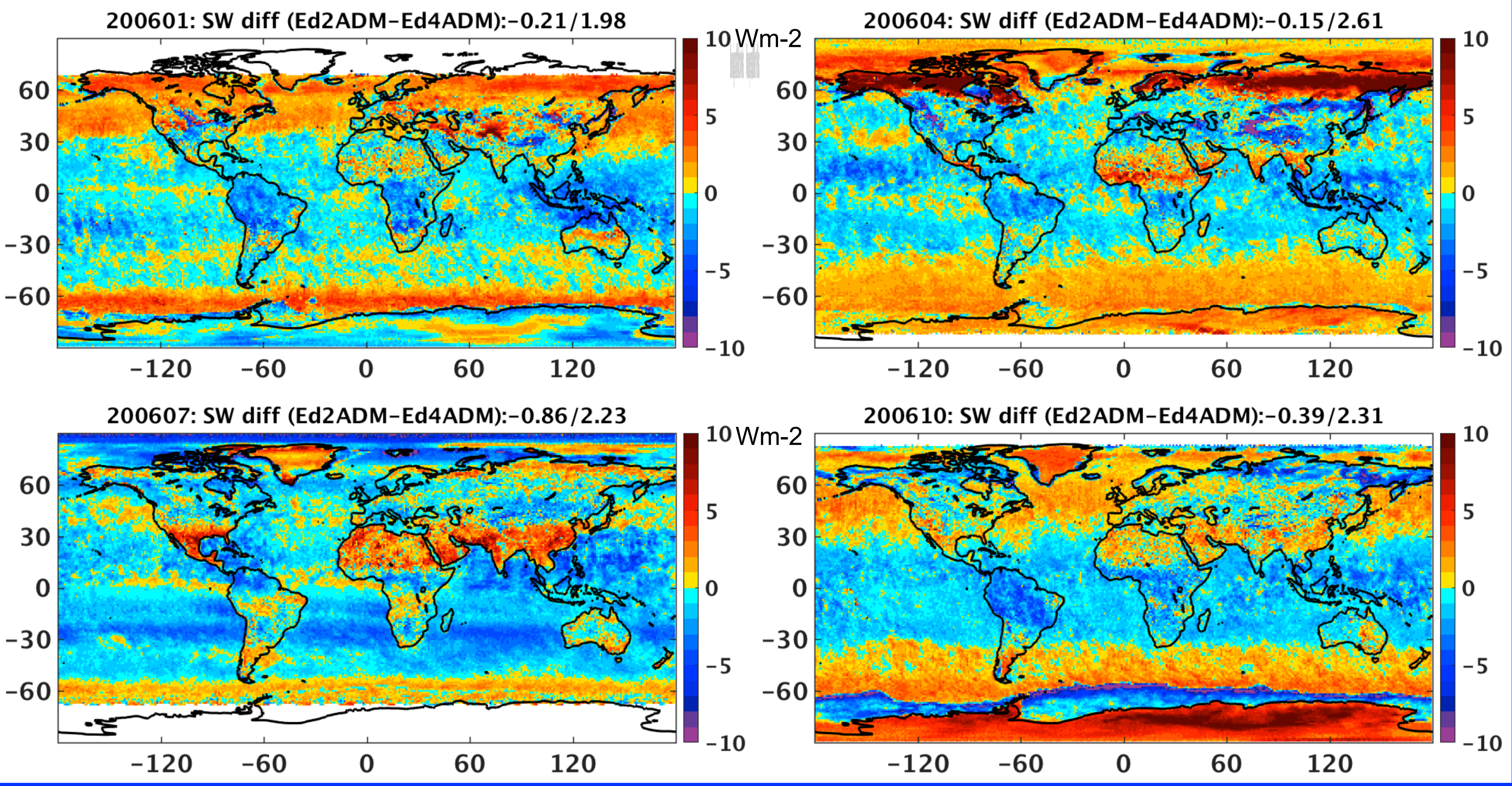
Nighttime

f

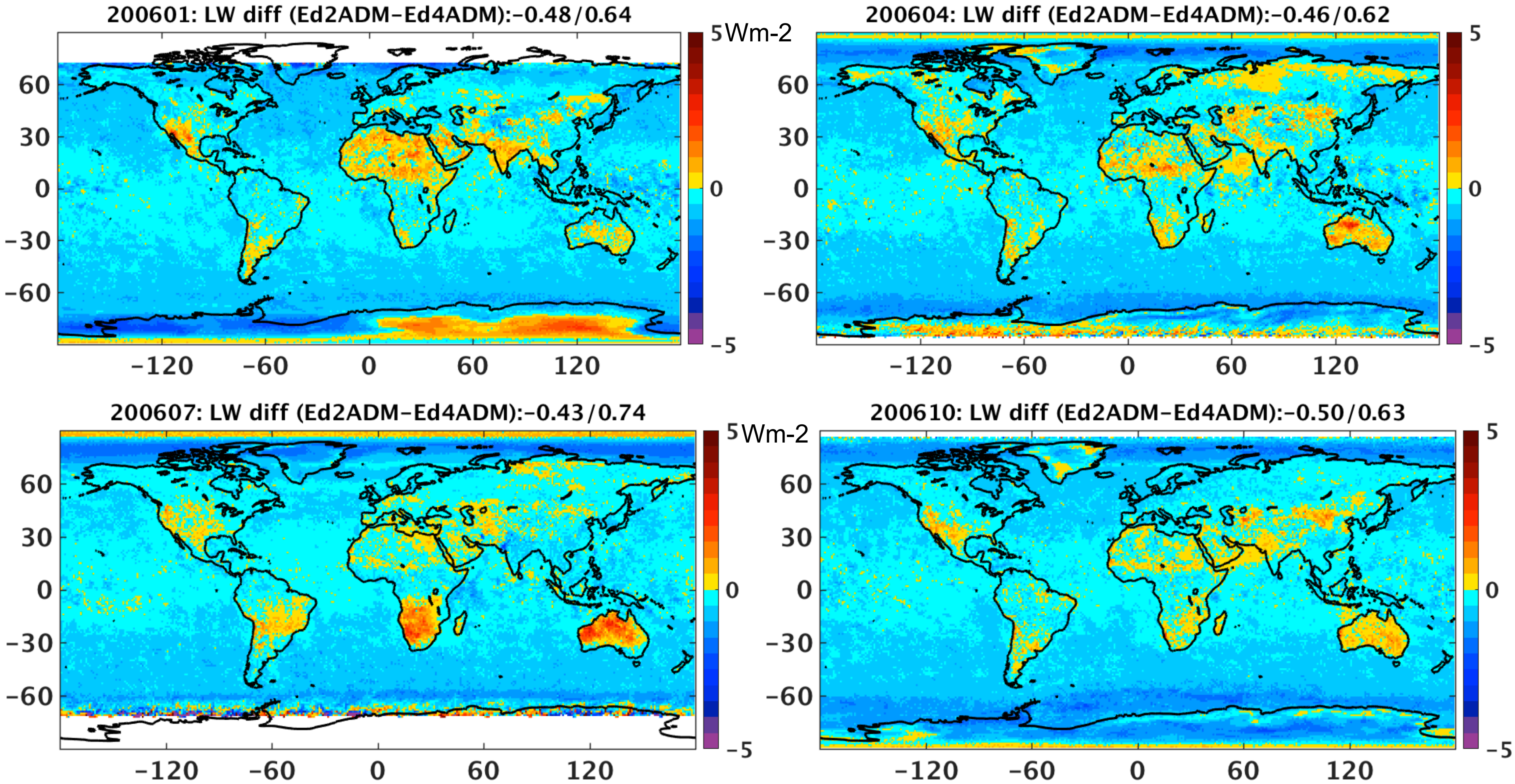
τ



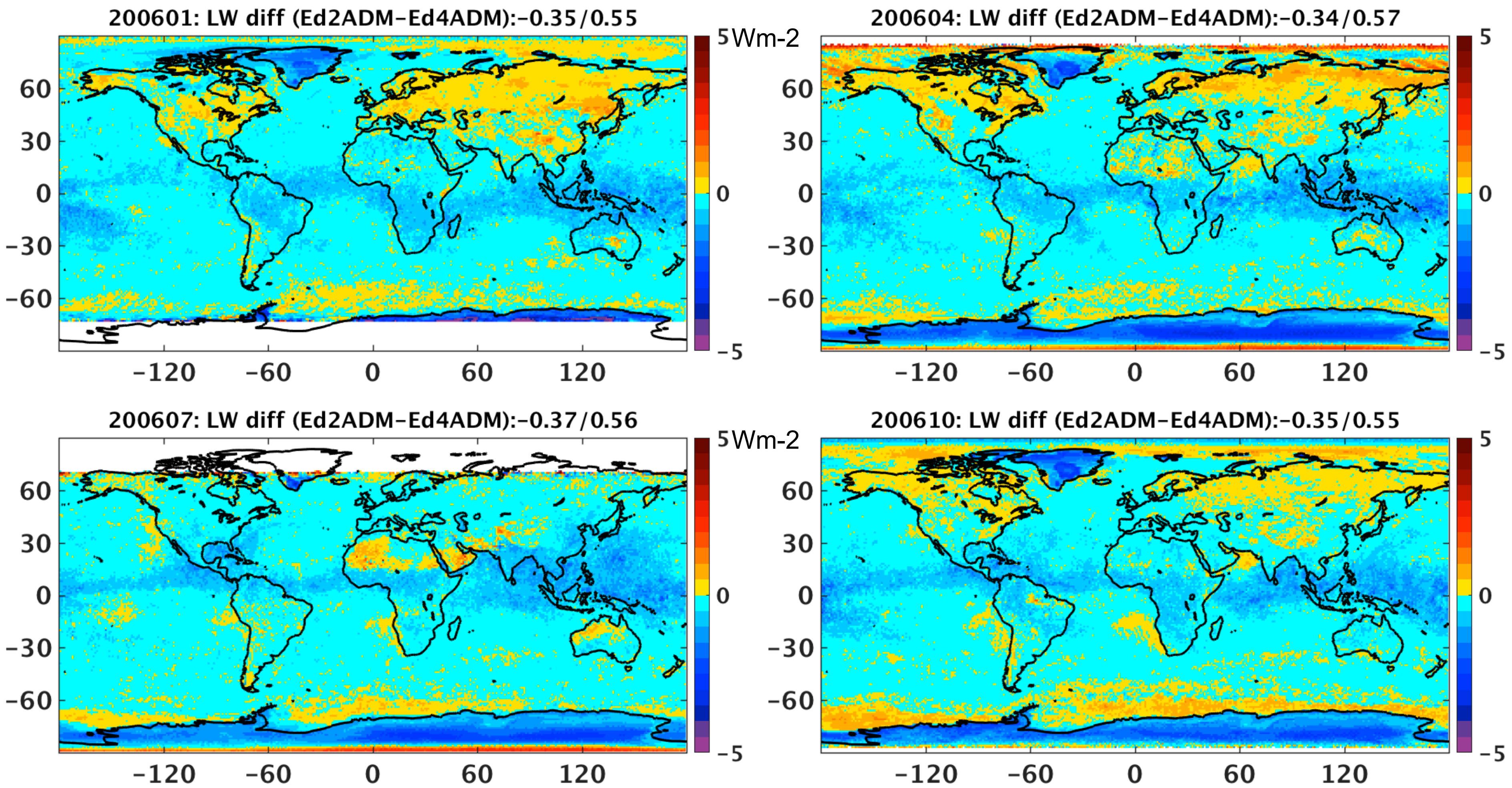
Monthly instantaneous SW flux difference: flux inverted from Ed2ADM – flux inverted from Ed4ADM



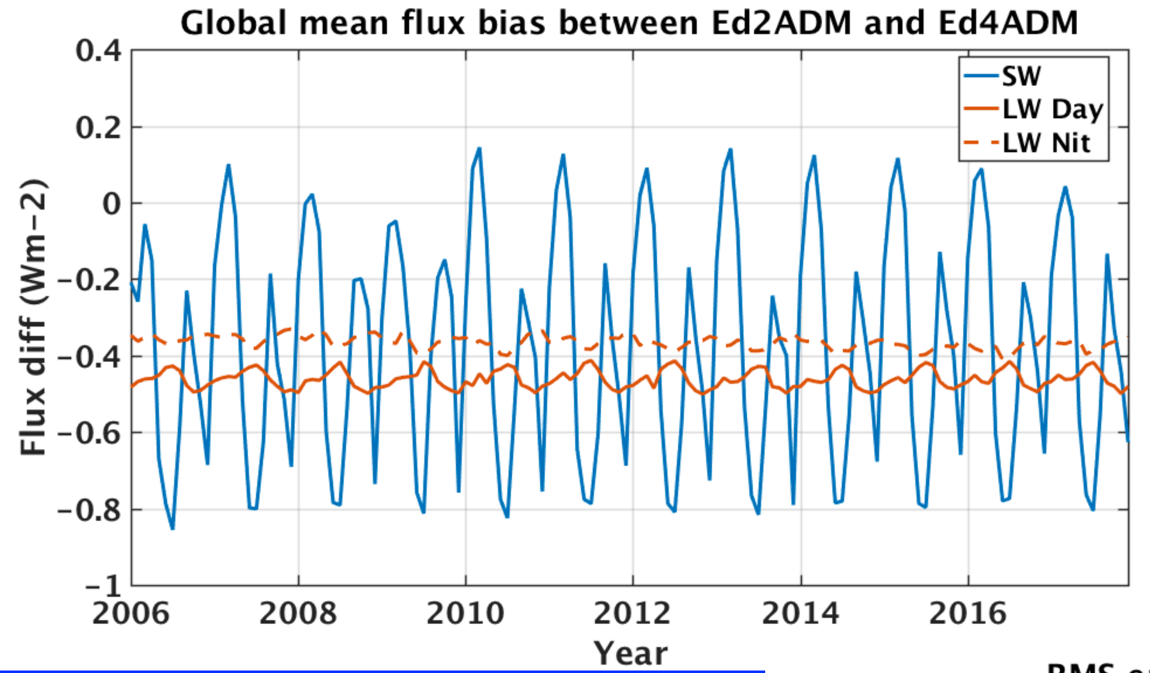
Monthly daytime LW flux difference: flux inverted from Ed2ADM – flux inverted from Ed4ADM

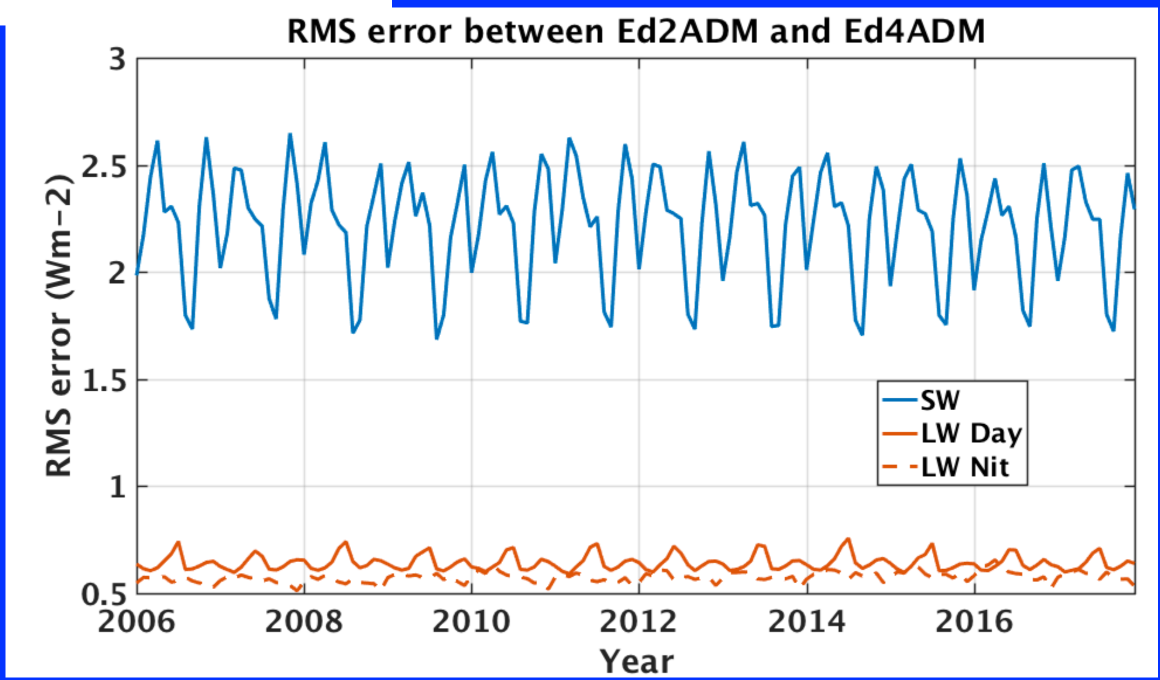


Monthly nighttime LW flux difference: flux inverted from Ed2ADM – flux inverted from Ed4ADM



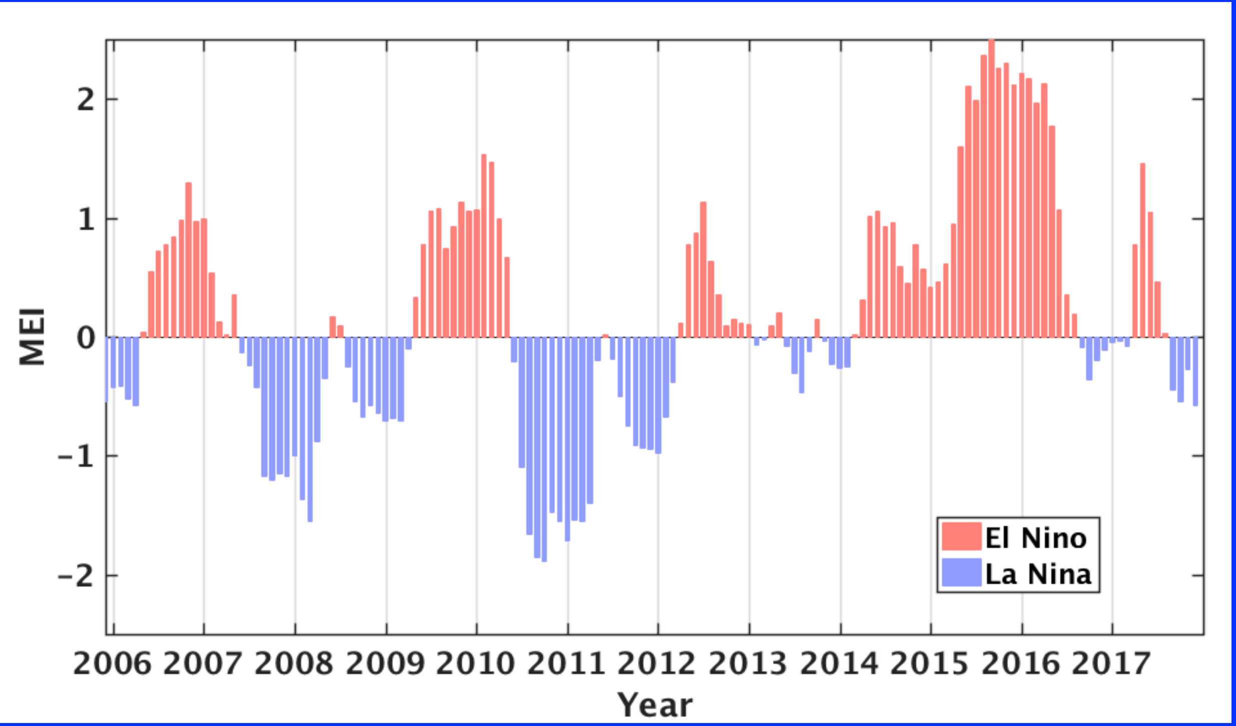
Monthly flux difference and RMS error



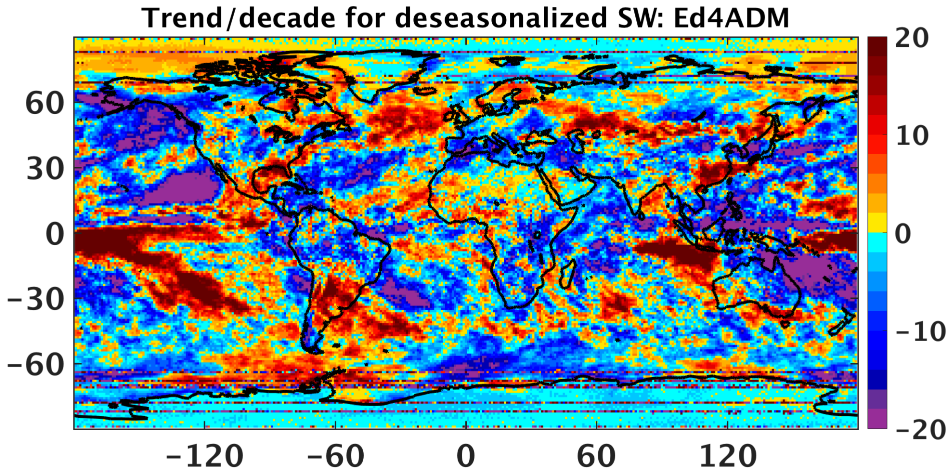


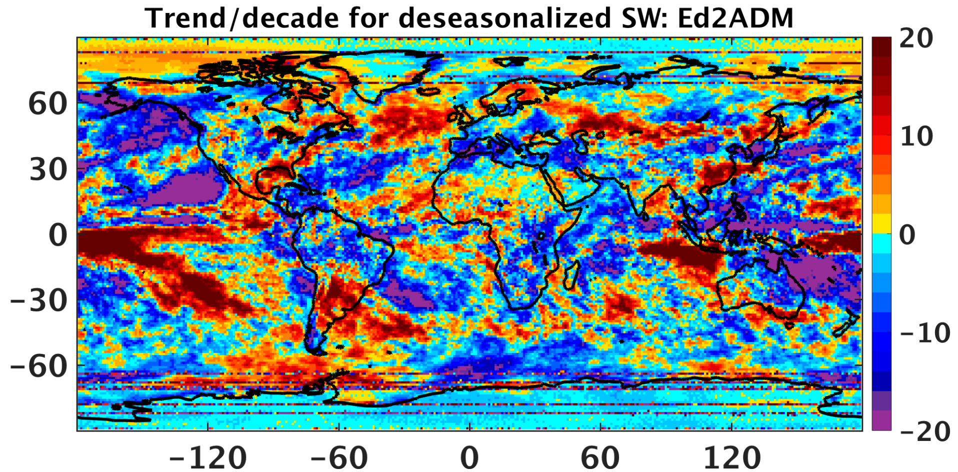
Instantaneous flux trend comparison: 2006-2017

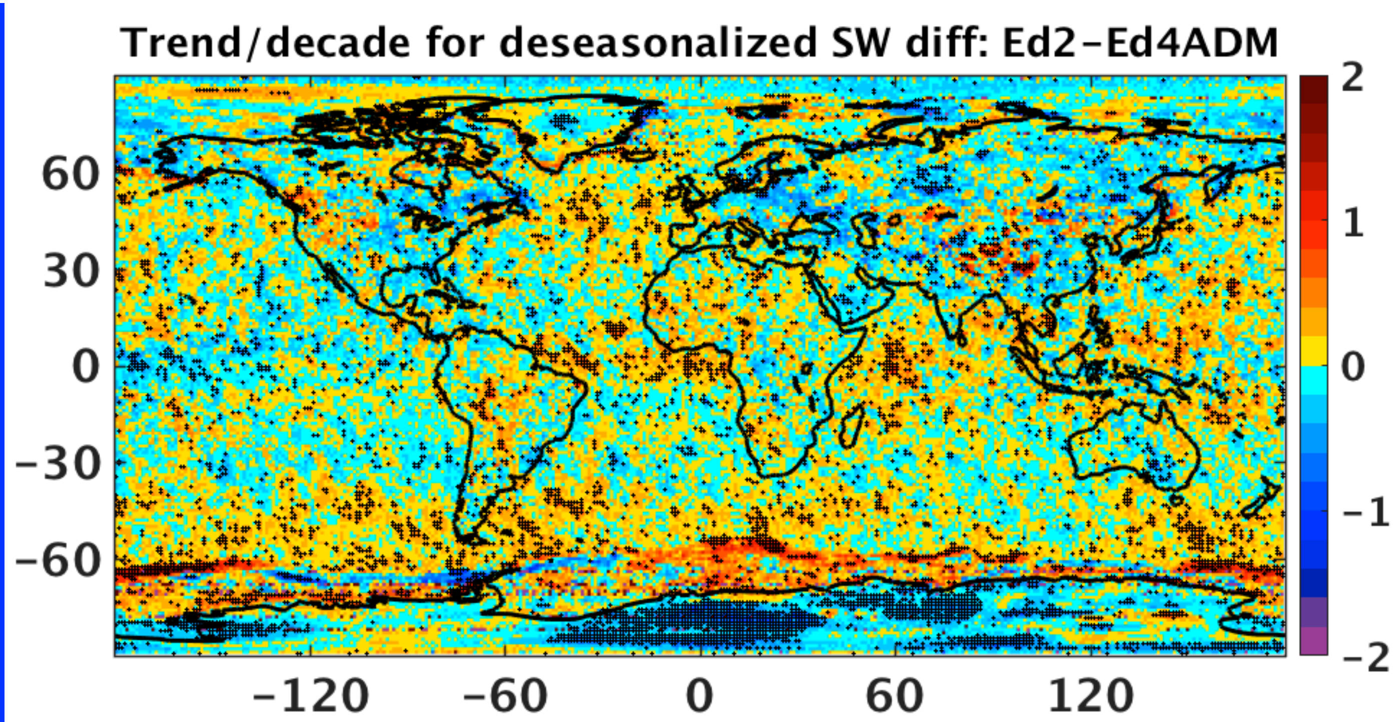
Wm-2 / decade	SW		Daytime LW		Nighttime LW	
	Ed4	Ed2	Ed4	Ed2	Ed4	Ed2
Global	-1.63±0.61	-1.59±0.61	0.58±0.27	0.57±0.27	0.41±0.21	0.39±0.21
60S-60N	-1.89±0.74	-1.87±0.74	0.48±0.35	0.48±0.35	0.40±0.28	0.37±0.28
30S-30N	-1.90±1.01	-1.86±1.01	0.55±0.46	0.55±0.46	0.49±0.40	0.46±0.40



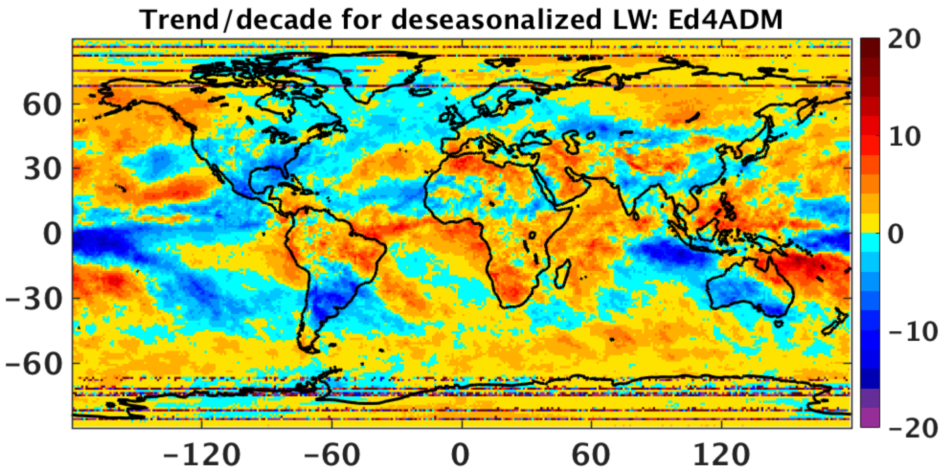
Instantaneous SW regional trend (Wm^{-2} per decade)

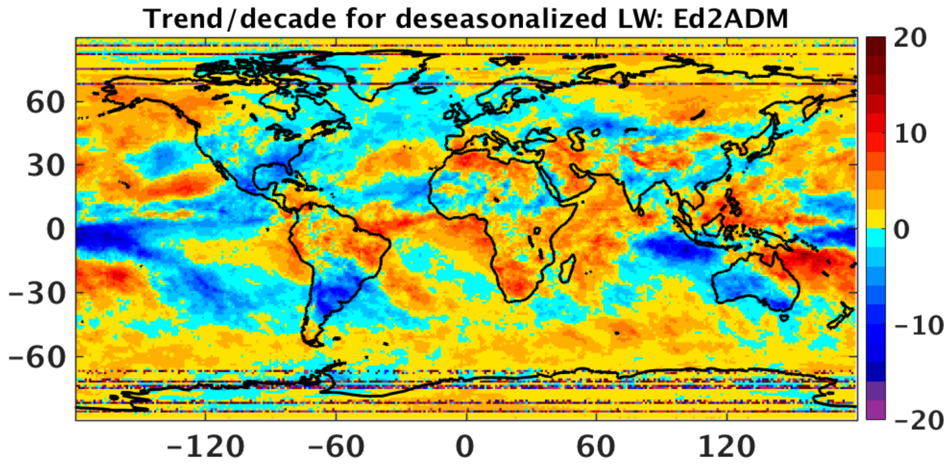


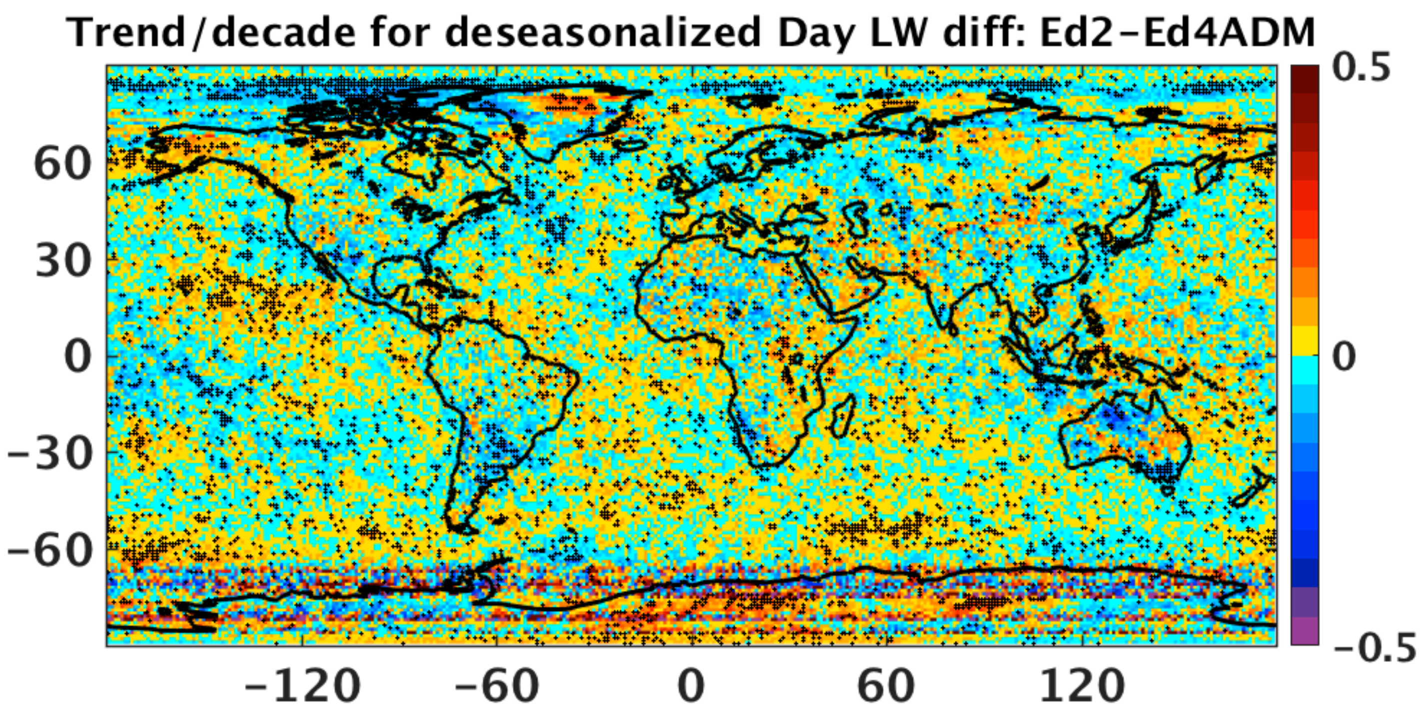




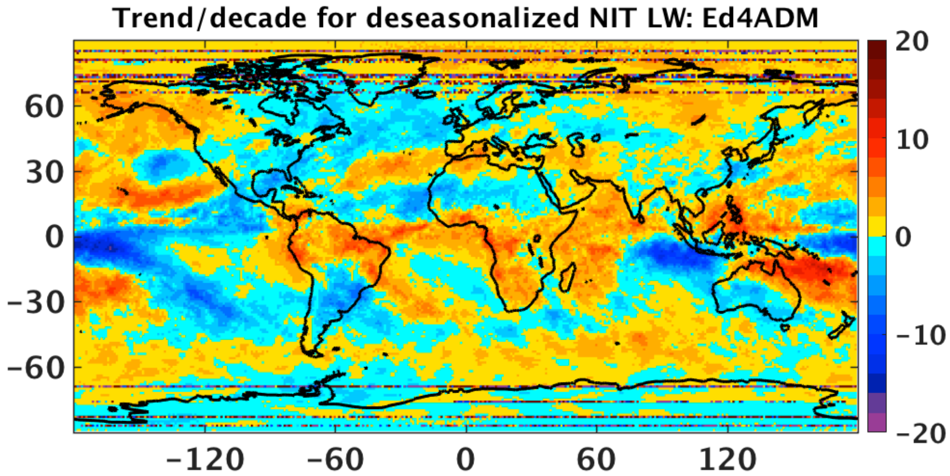
Daytime LW regional trend (Wm^{-2} per decade)

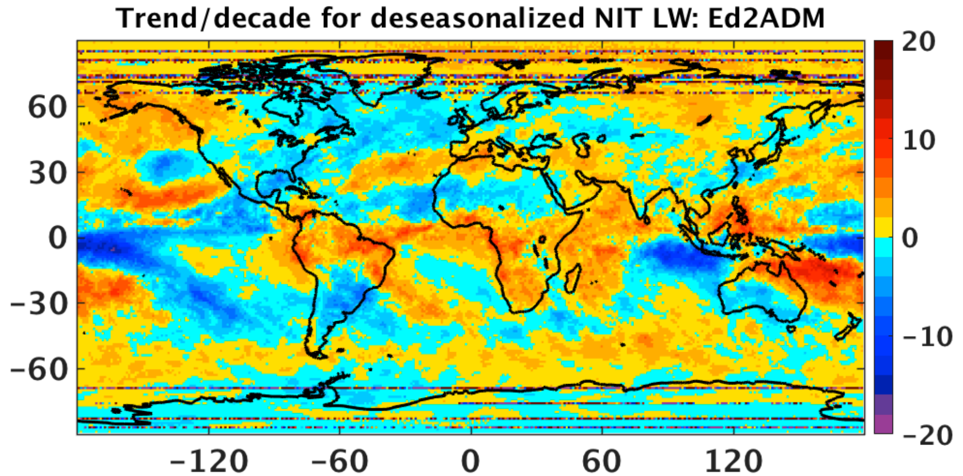


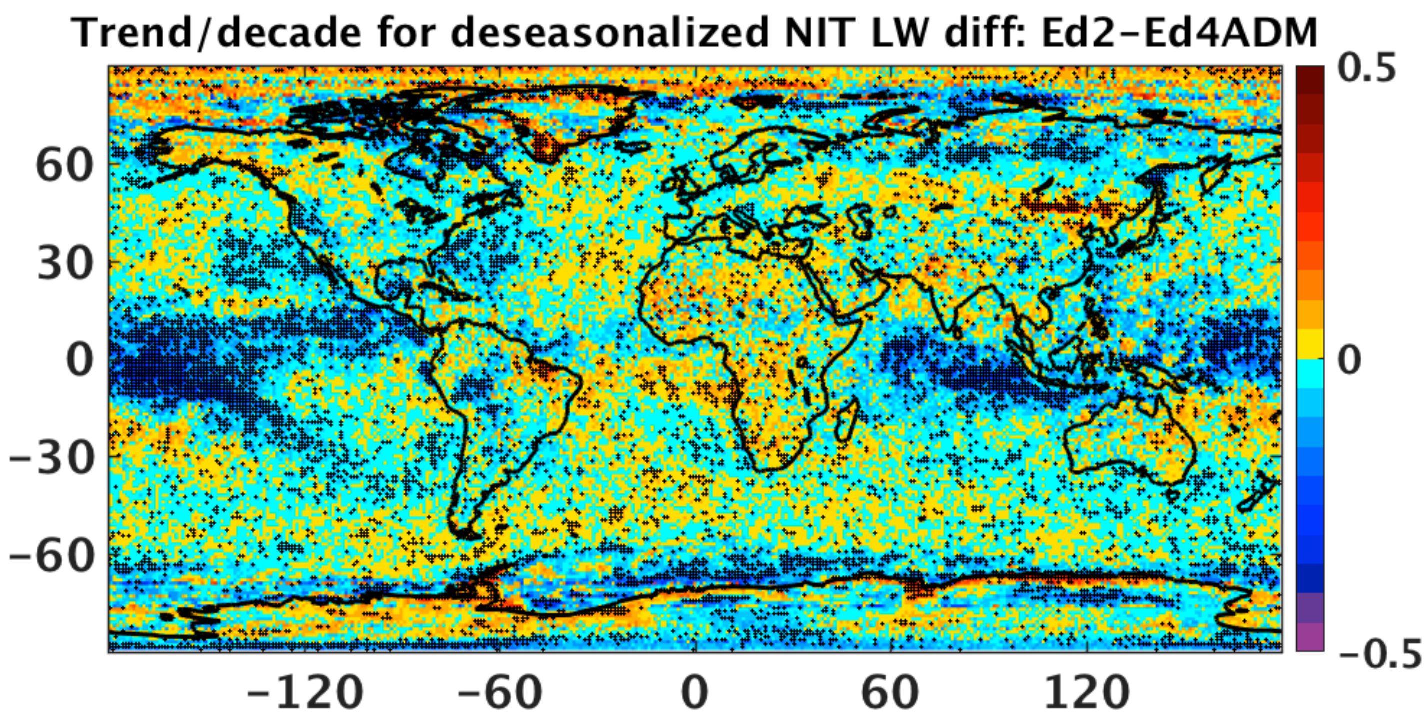




Nighttime LW regional trend (Wm^{-2} per decade)







Future plan for angular distribution model development

- Account for inhomogeneity of clouds (using standard deviation of cloud optical depth within the CERES footprint) when developing ADMs over cloudy scenes;
- Consider more phase separations for mixed phase clouds (mostly water, water-ice, mostly ice, etc.);
- Examine if it is necessary to develop ADMs for single-layer and multi-layer clouds separately;
- Account for sastrugi for clear and partly-cloudy ADMs over Greenland and Antarctic;
- Investigate better ways to identify fresh snow and possibly including snow depth in developing fresh snow ADMs;
- Investigate if solar zenith angle and azimuth angle need to be considered for clear-sky daytime LW ADMs.

Angular distribution model over cloudy ocean

- For glint angle > 20°, or glint angle < 20° and ln(fτ) > 6:
  - Average instantaneous radiances in each angular bin into 775 intervals of ln(fτ), separately for liquid, mixed, and ice clouds;

$$\overline{\rho} = \frac{f_1 \rho_1 + f_2 \rho_2}{f_1 + f_2} \longrightarrow$$

Liquid: $\overline{\rho} < 1.01$

Mixed: $1.01 \leq \overline{\rho} \leq 1.75$

Ice: $\overline{\rho} > 1.75$

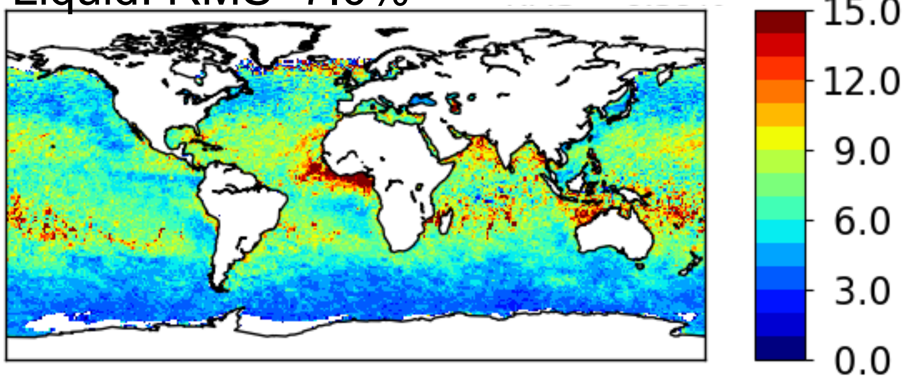
  - Apply a five-parameter sigmoidal fit to mean radiance and ln(fτ);

$$I = I_0 + \frac{a}{[1 + e^{-(x - x_0)/b}]^c}$$

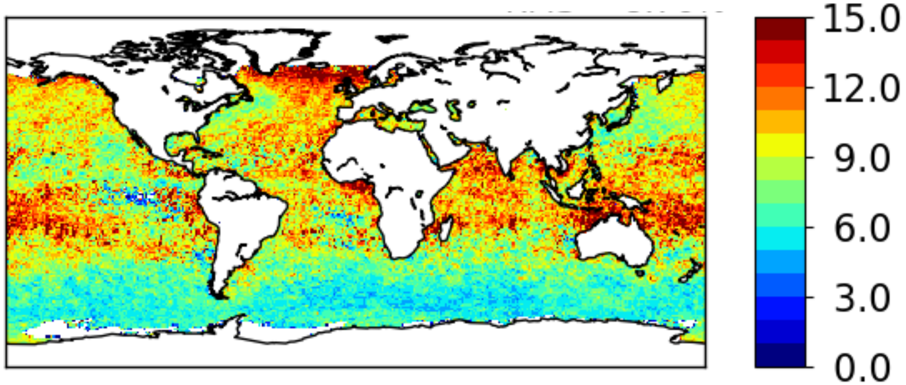
Normalized RMS error calculated using ADMs constructed for three cloud phases

- RMS error between normalized ADM predicted radiance and normalized observed radiance is closely related to the ADM error;
- Mixed phase clouds have the largest RMS error, and ice clouds have the smallest RMS error.

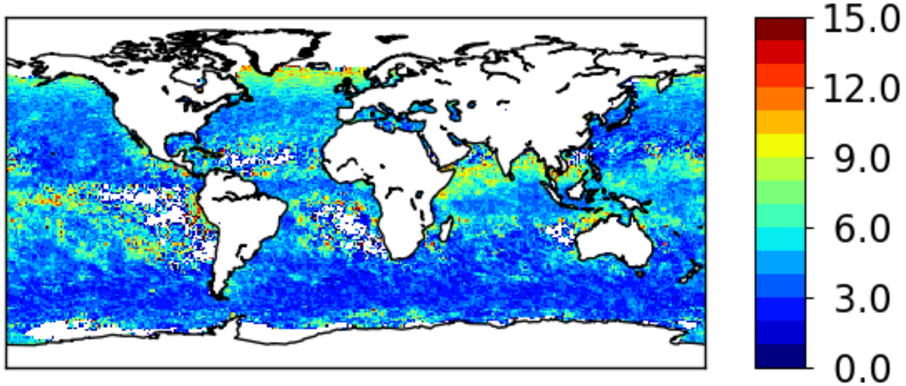
Liquid: RMS=7.0%



Mixed: RMS=9.1%



Ice: RMS=4.5%



Types of clouds over ocean: daytime retrievals from four seasonal months of 2008

Single layer clouds: Liquid (39.6%), mixed (5.9%), ice (6.2%)

Two layer clouds:

Liquid over liquid (2.7%)	Mixed over liquid (0.9%)	Ice over liquid (43.2%)
Liquid over mixed (0.1%)	Mixed over mixed (0.2%)	Ice over mixed (0.3%)
Liquid over ice (0.001%)	Mixed over ice (0.3%)	Ice over ice (0.9%)

- Single layer clouds contribute about 51.7%
- Mixed phase clouds contribute about 7.6%
- Most of the ice clouds are over liquid clouds (43.2% compares to 6.2% single layer ice clouds)

Redefine the mixed and ice clouds

- Cloud phases are defined as:

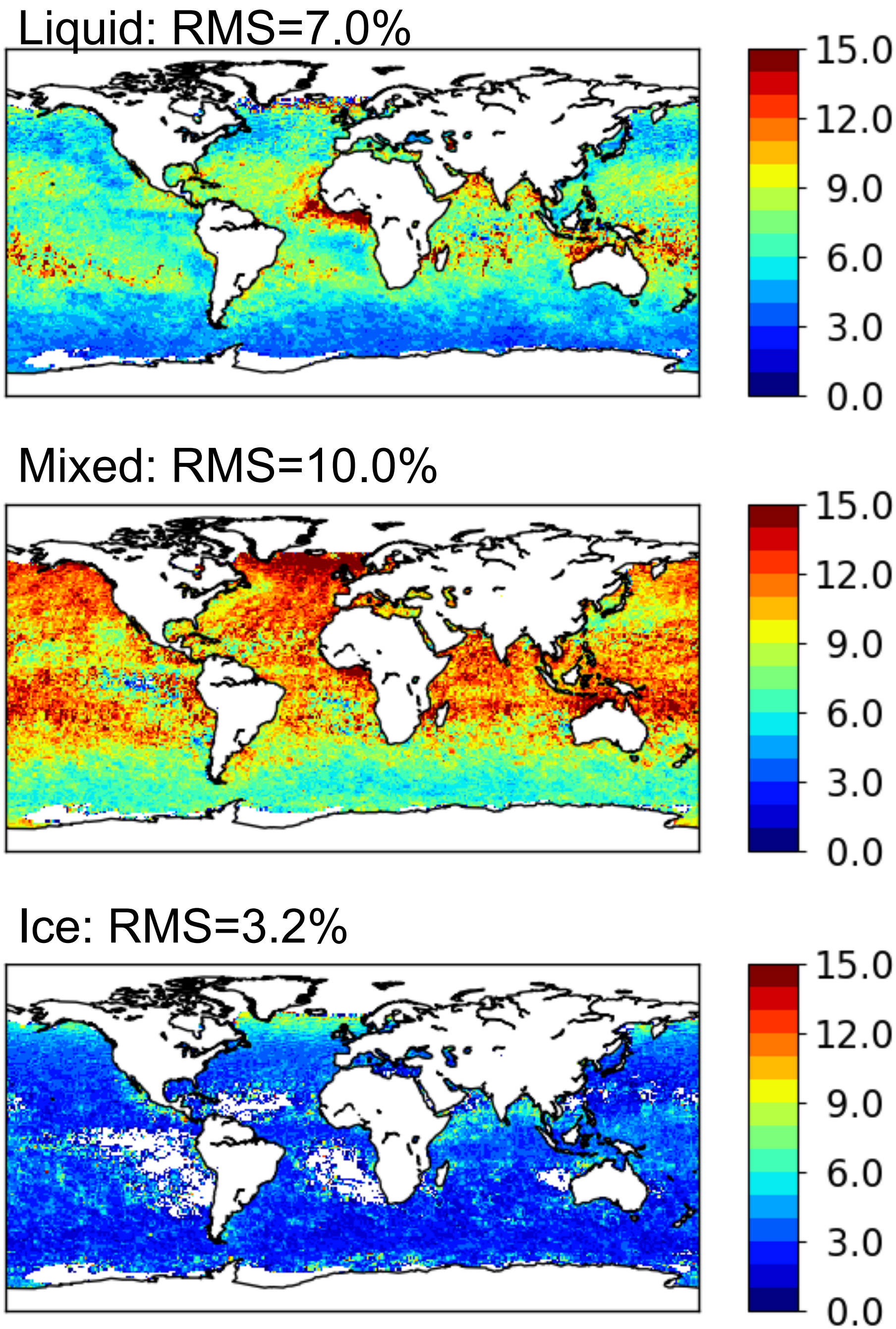
  Liquid: $\overline{\rho} < 1.01$

  Mixed: $1.01 \leq \overline{\rho} \leq 1.95$

  Ice: $\overline{\rho} > 1.95$

- Changing the ice phase definition towards higher phase value (less mixed clouds) reduced the RMS error from 4.5% to 3.2%;

- However, the RMS error for the mixed phase increased from 9.1% to 10.0%.



Split mixed clouds into two categories

- As most of the mixed clouds are from ice over water case, mixed clouds are further stratified into two categories:

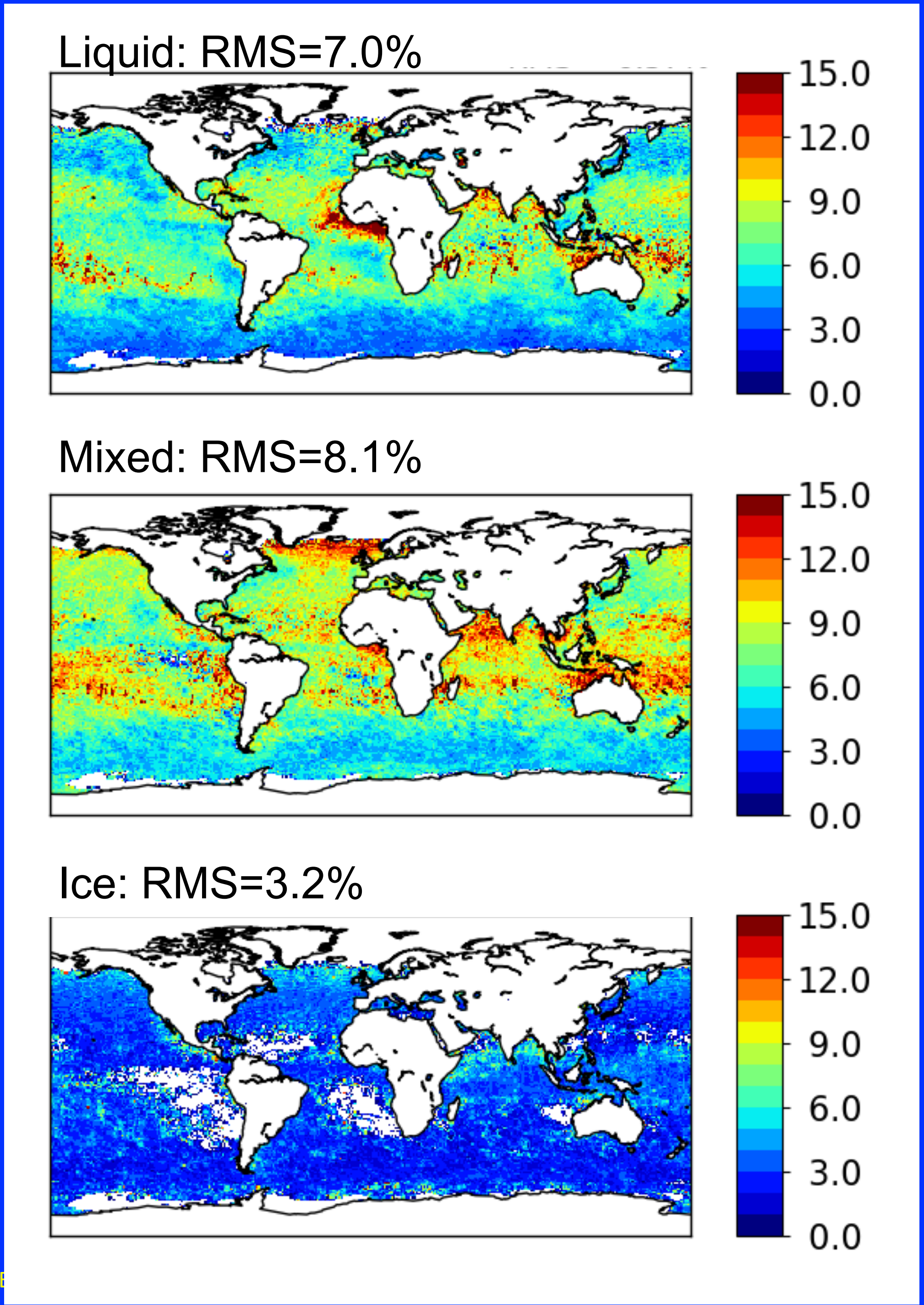
  Liquid: $\overline{\rho} < 1.01$

  Mixed 1: $1.01 \le \overline{\rho} < 1.30$

  Mixed 2: $1.30 \le \overline{\rho} \le 1.95$

  Ice: $\overline{\rho} > 1.95$

- The RMS error for the mixed phase clouds is the lowest among the different stratifications that we tested.



Summary

- The beginning of the mission spectral response function for CERES-NPP will be refined to account for the scene dispersion, and new radiometric adjustment gains will be produced for CERES-NPP to place CERES-NPP and CERES-Aqua on the same radiometric scale;
- Using Ed2ADM to produce Ed4 fluxes:
  - Monthly gridded instantaneous SW fluxes differ by up to 10 Wm^{-2}, and monthly gridded LW fluxes differ by about 2 Wm^{-2}.
  - Biases in global monthly mean SW fluxes range from -0.8 to 0.2 Wm^{-2} and the RMS errors are from 1.7 to 2.6 Wm^{-2}. Biases in global monthly mean LW fluxes are about -0.5 Wm^{-2} and the RMS errors are about 0.7 Wm^{-2}.
  - Similar global-mean trends, but regional trends show some statistically significant differences.
- Separate the mixed phase clouds into two types further improves the cloudy-ocean ADMs.